Weak Gravitational Lensing and Cluster Counts

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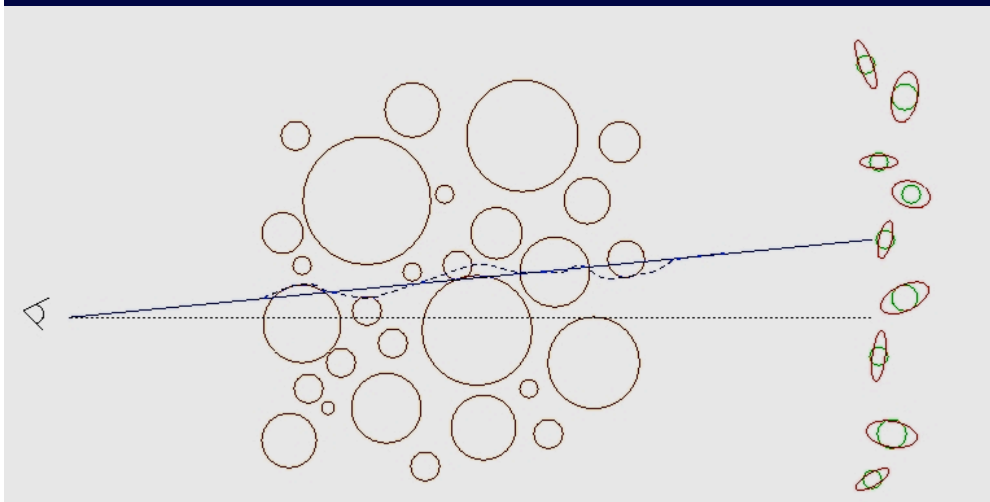
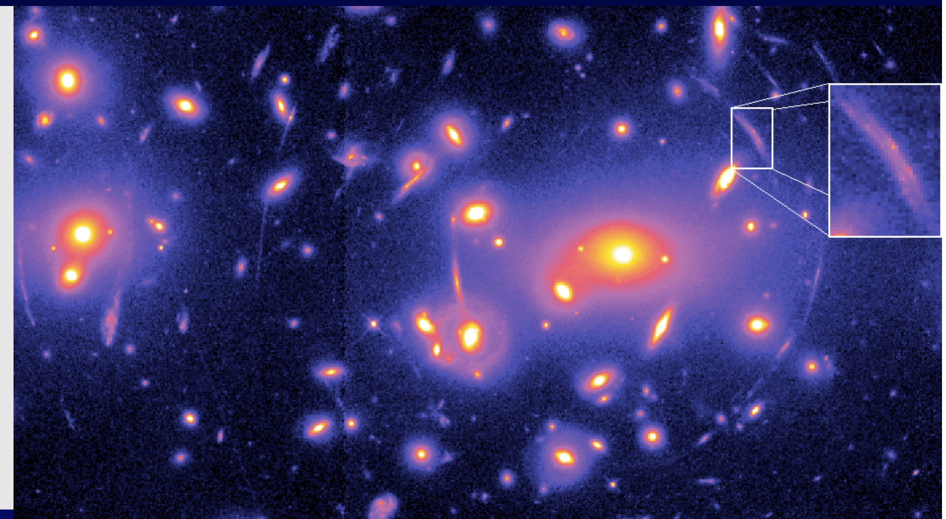
Beyond Einstein – SLAC – May 2004

Weak Gravitational Lensing





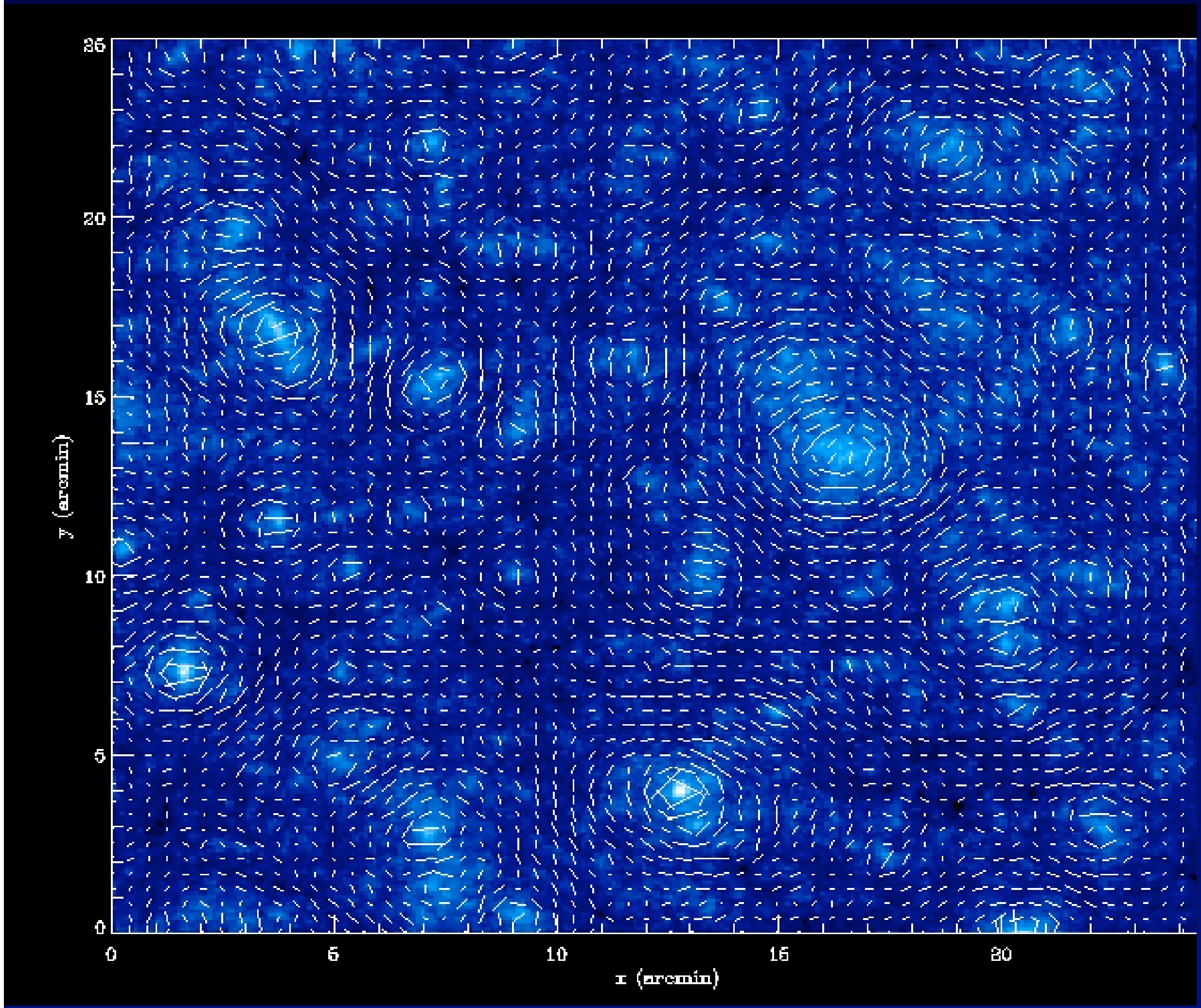
Distortion Matrix: $$\Psi_{ij} = \frac{\partial \delta\theta_i}{\partial \theta_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j}$$

Theory

→ Direct measure of the distribution of mass in the universe, as opposed to the distribution of light, as in other methods (eg. Galaxy surveys)

Scientific Promise of Weak Lensing

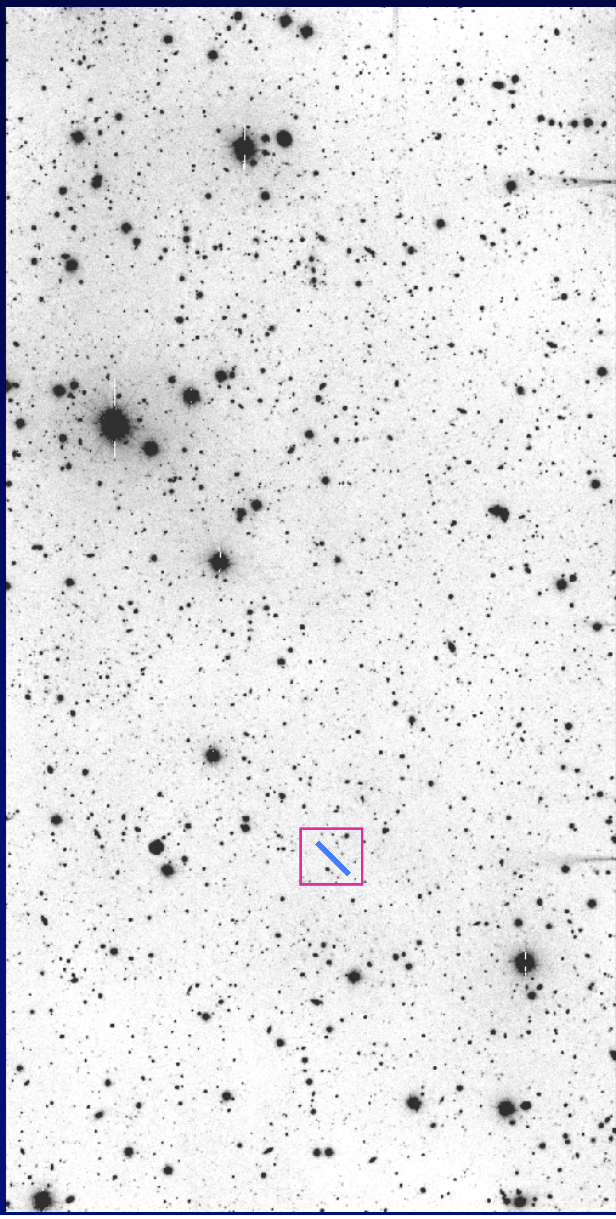
From the statistics of the shear field, weak lensing provides:



- Mapping of the distribution of Dark Matter on various scales
- Measurement of the evolution of structures
- Measurement of cosmological parameters, breaking degeneracies present in other methods (SNe, CMB)
- Explore models beyond the standard osmological model (ΛCDM)

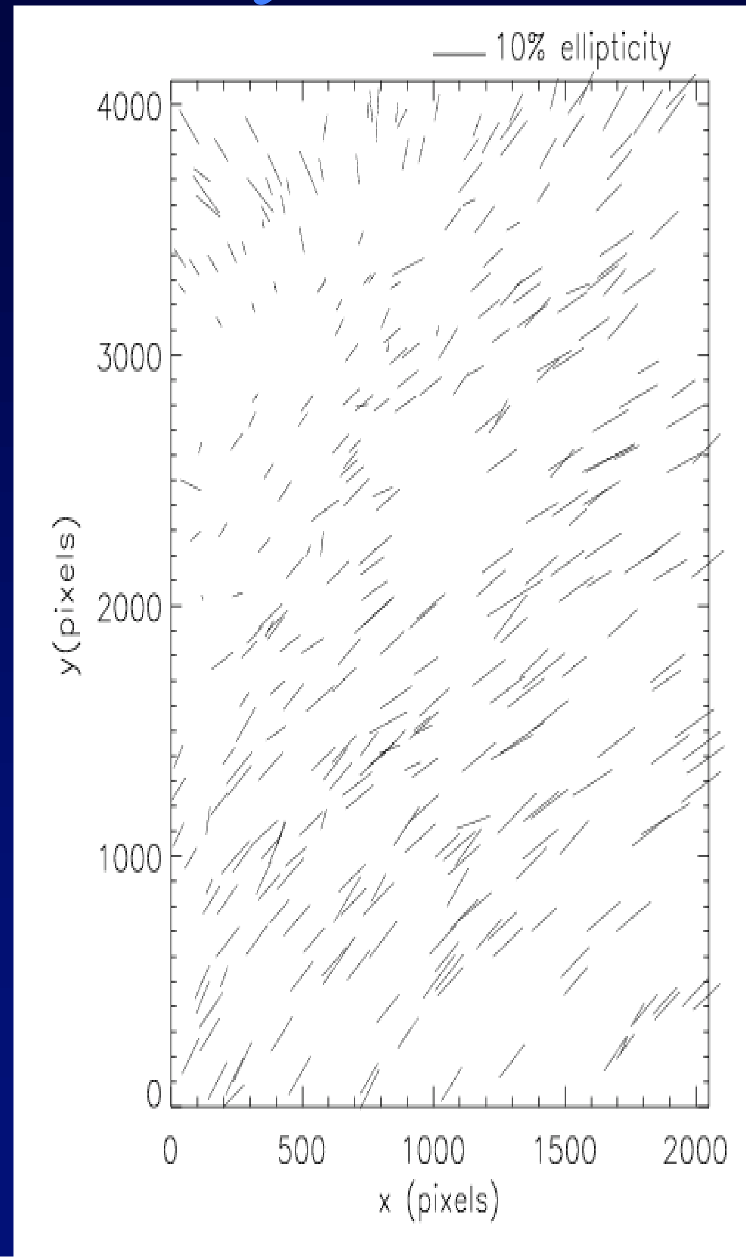
Jain, Seljak & White 1997, 25’x25’, SCDM

Cosmic Shear Surveys

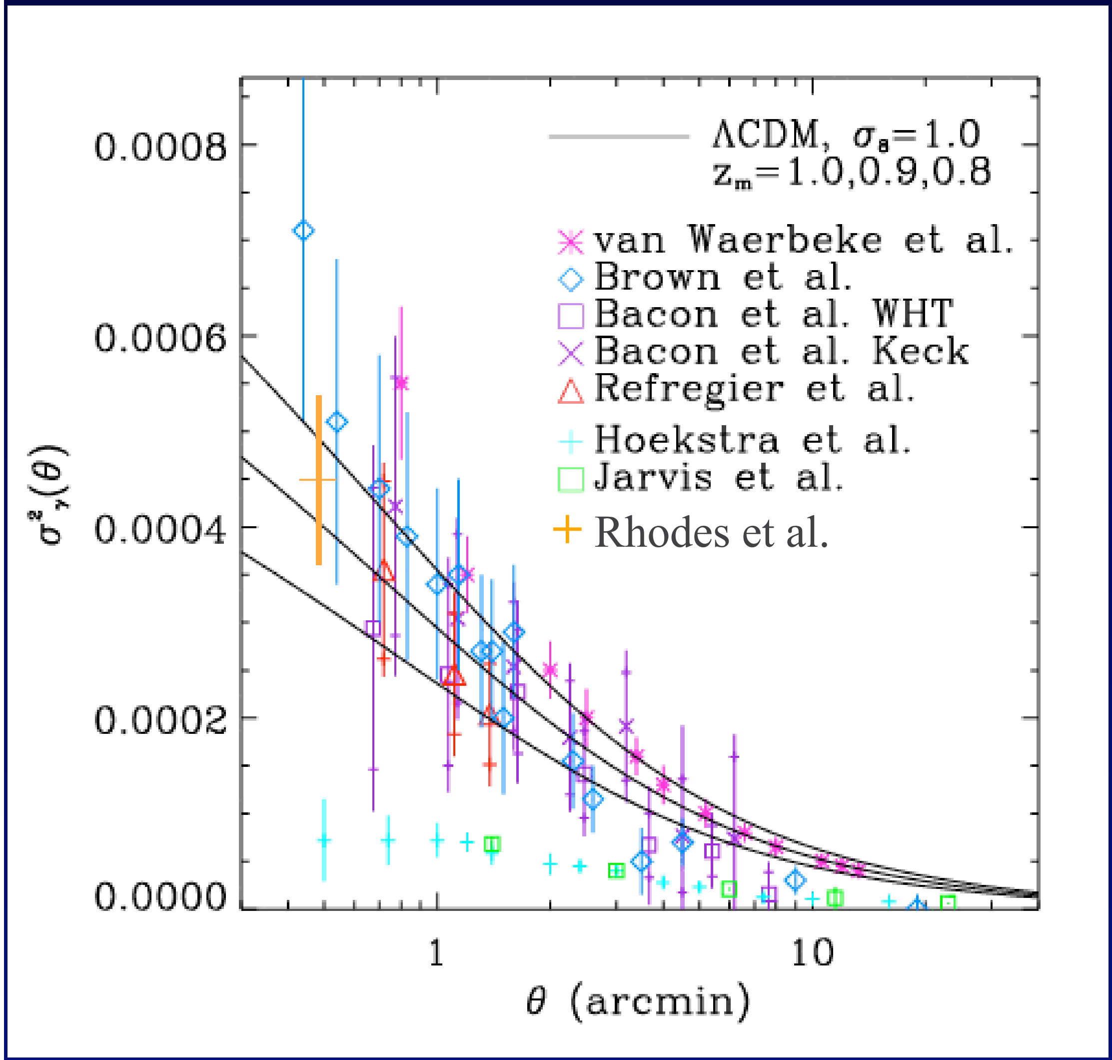


WHT survey:
16'x8'
R<25.5
20 gals/amin^2

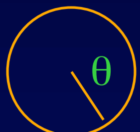
Systematics:
Anisotropic
PSF



Cosmic Shear Measurements



Shear variance in circular cells:



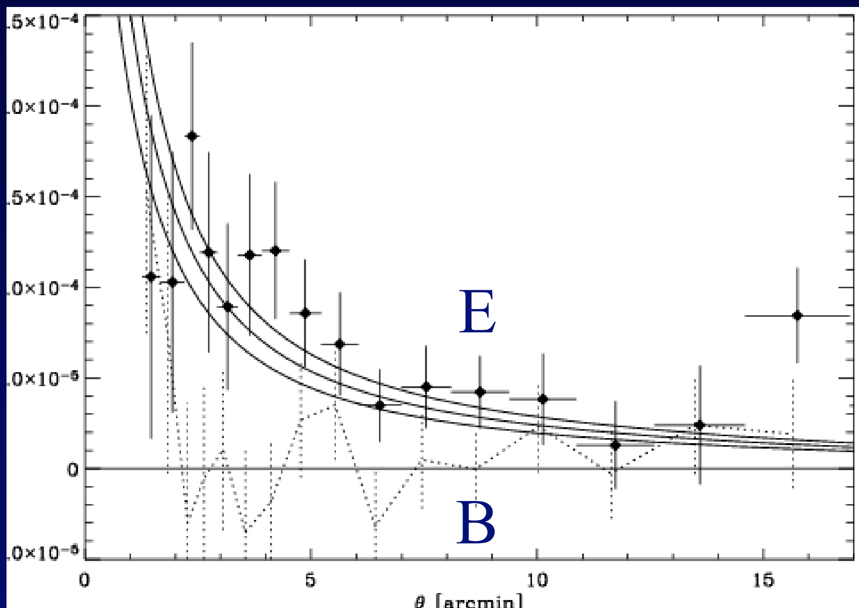
$\sigma^2_\gamma(\theta) = \langle\gamma^2\rangle$

Bacon, Refregier & Ellis 2000*
Bacon, Massey, Refregier, Ellis 2001
Kaiser et al. 2000*
Maoli et al. 2000*
Rhodes, Refregier & Groth 2001*
Refregier, Rhodes & Groth 2002
van Waerbeke et al. 2000*
van Waerbeke et al. 2001
Wittman et al. 2000*
Hammerle et al. 2001*
Hoekstra et al. 2002 *
Brown et al. 2003
Hamana et al. 2003 *
Jarvis et al. 2003
Casertano et al 2003*
Rhodes et al 2004
Massey et al. 2004*

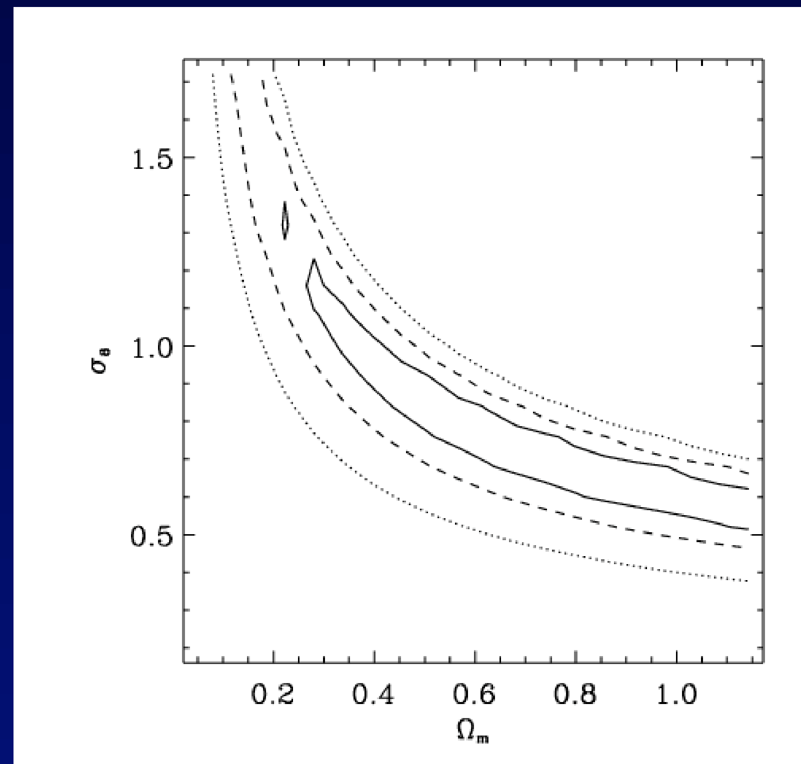
* not shown

Cosmological Constraints

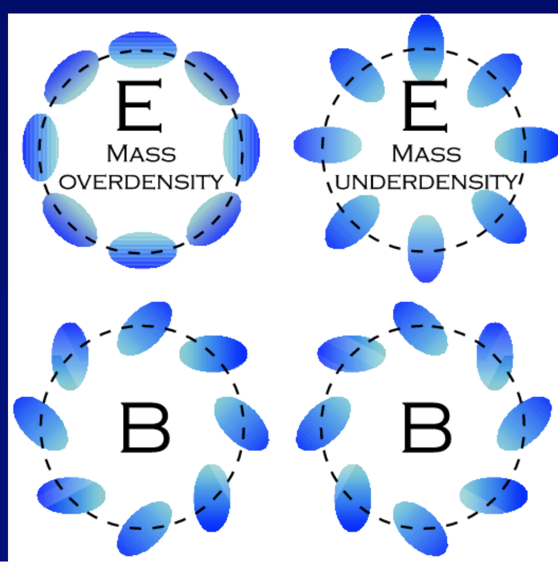
Shear correlation functions



Massey, Refregier, Bacon & Ellis 2004

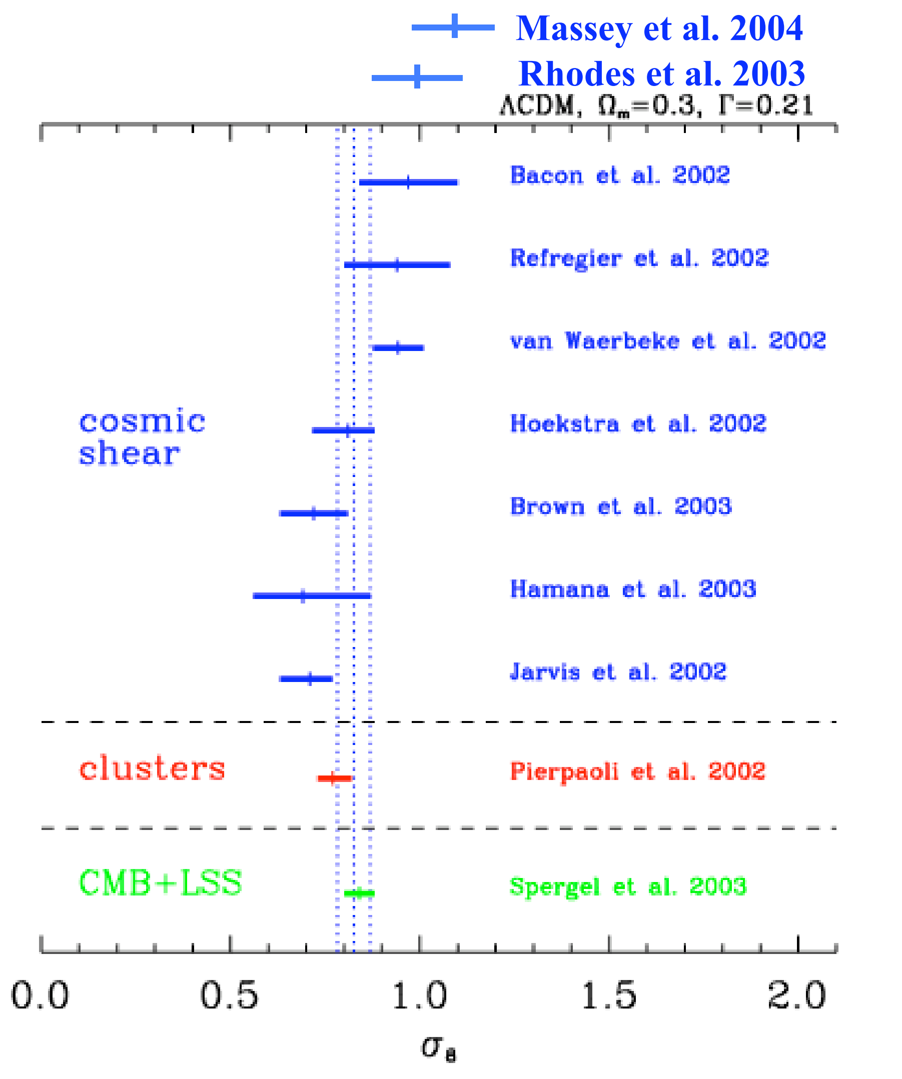


E/B decom- position



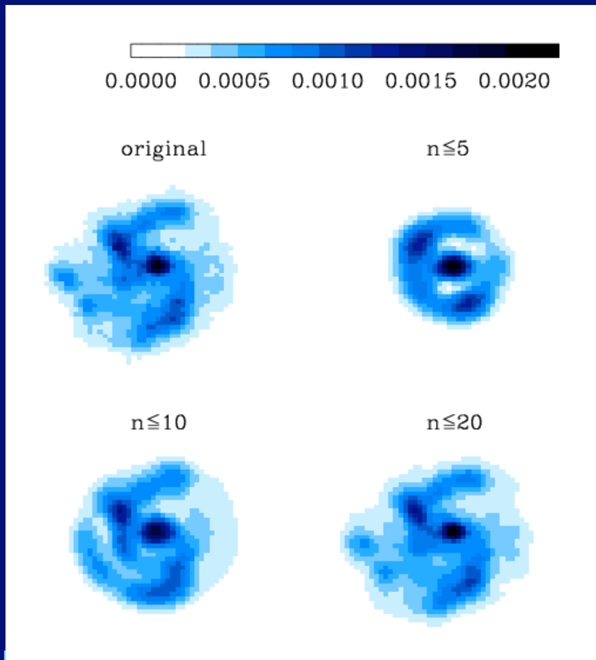
$$\sigma_8 \left(\frac{\Omega_m}{0.3} \right)^{0.51} = 1.09 \pm 0.12$$

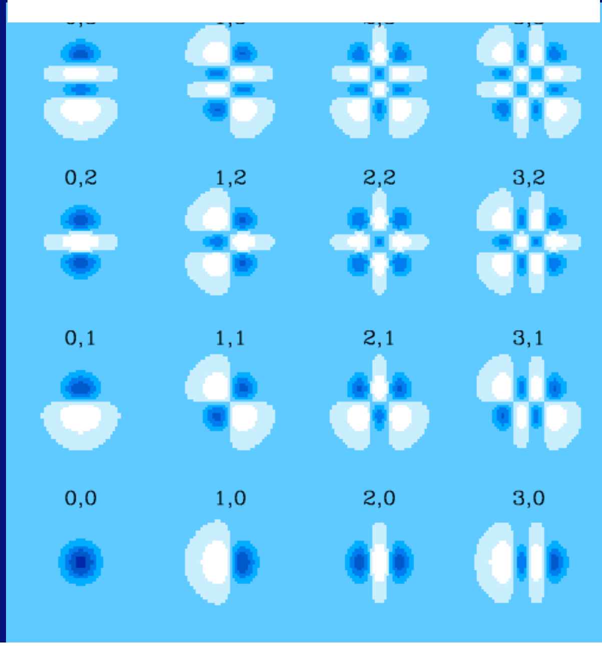
Normalisation of the Power Spectrum



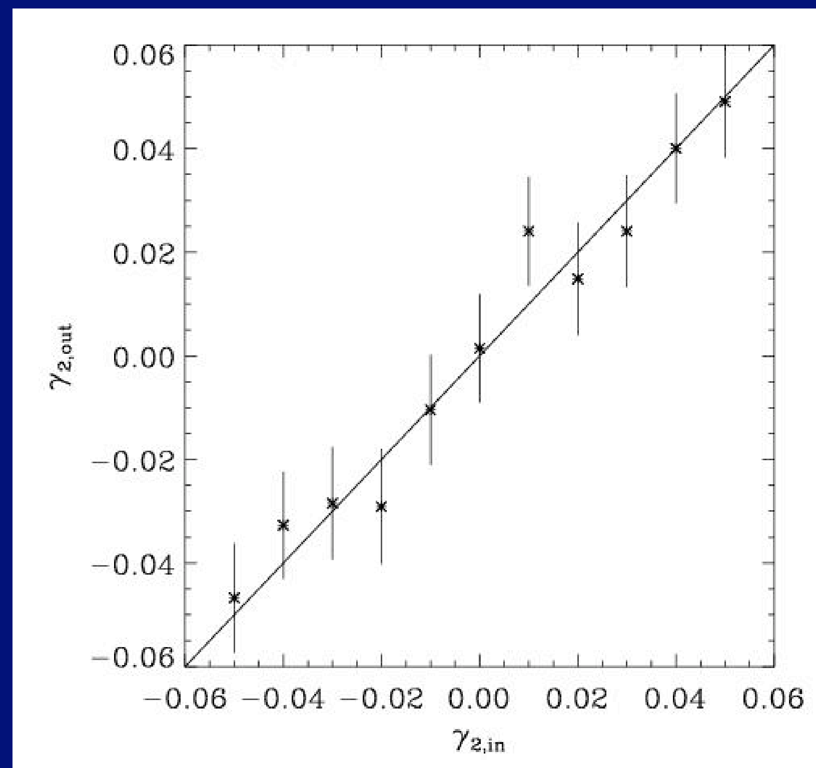
→ Moderate disagreement among cosmic shear measurements
(careful with marginalisation)
→This could be due to residual systematics (shear calibration?)
→Agreement on average with CMB constraints
→ moderate inconsistency with cluster abundance
(systematics or new physics?)

Shear Measurement: Shapelets





Methods: Kaiser, Squires & Broadhust (1995), Kuijken (1999), Kaiser (2000), Rhodes, Refregier & Groth (2000), Bridle, Marshall et al. (2001), Refregier & Bacon (2001), Bernstein & Jarvis (2001)

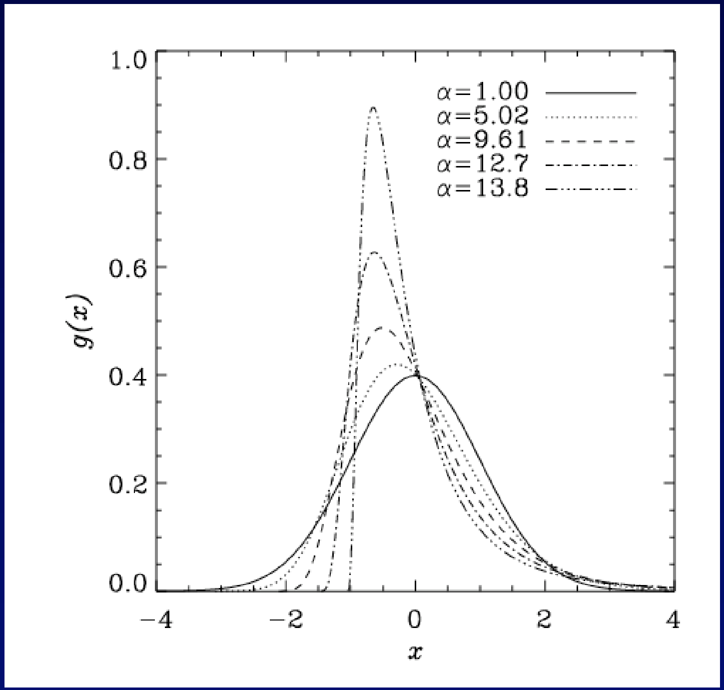


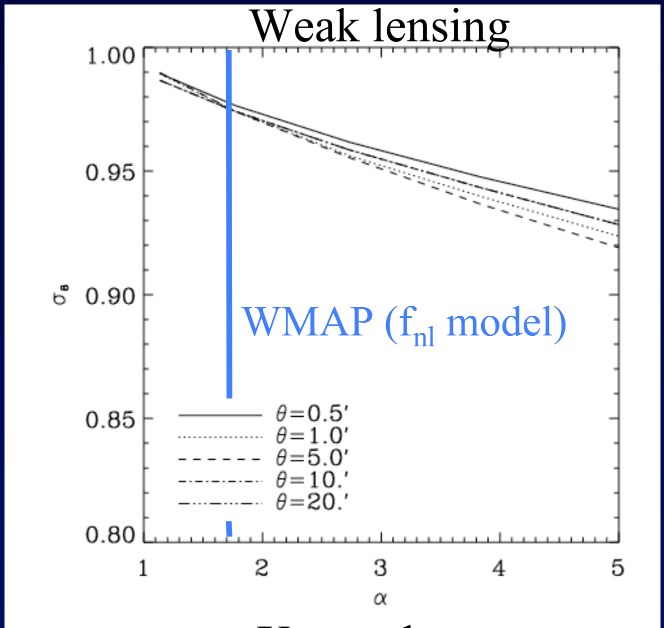
→ Joint analysis of COSMOS field:
with HST/ACS, CFHT, Subaru

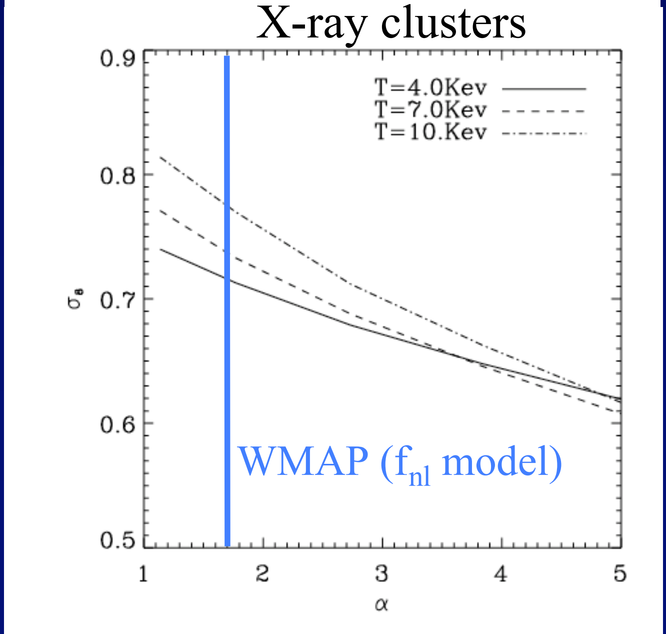
Primordial Non-Gaussianity

Amara & Refregier 2003

Primordial density PDF



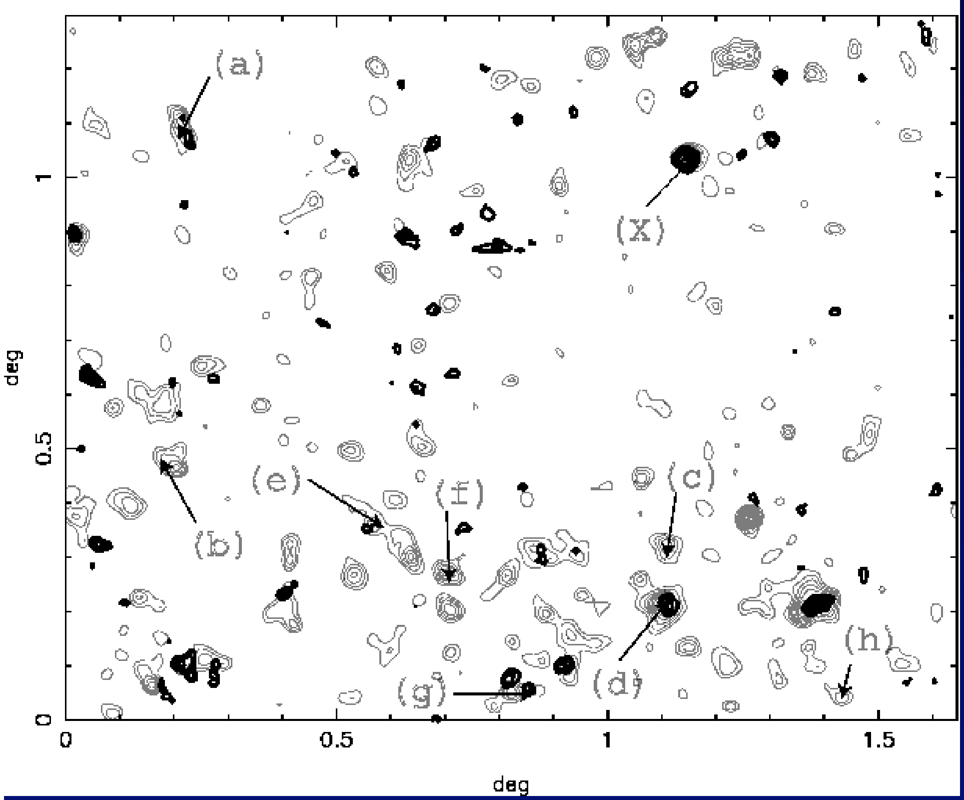


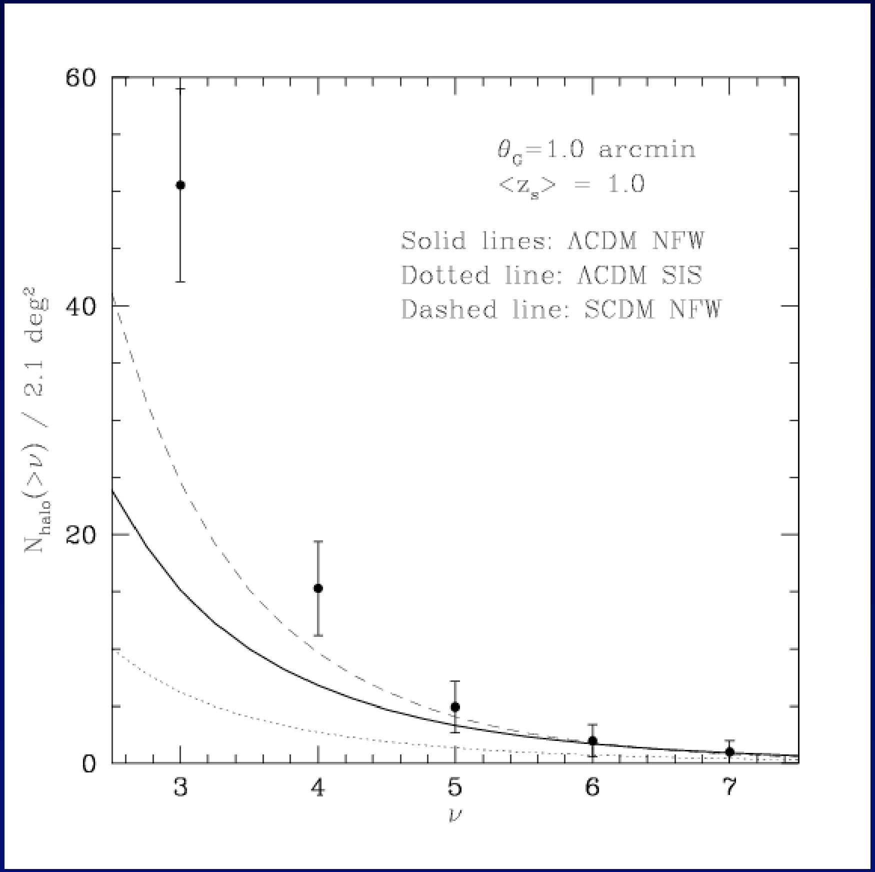


- Need strong non-gaussianity to explain scatter in σ_8
- Not compatible with WMAP limit assuming the quadratic coupling model (Komatsu et al. 2003)
- Scatter more likely due to systematics or other physics

Mass-Selected Clusters

Miyazaki et al. 2002 — 2.1 deg^2 survey with Subaru



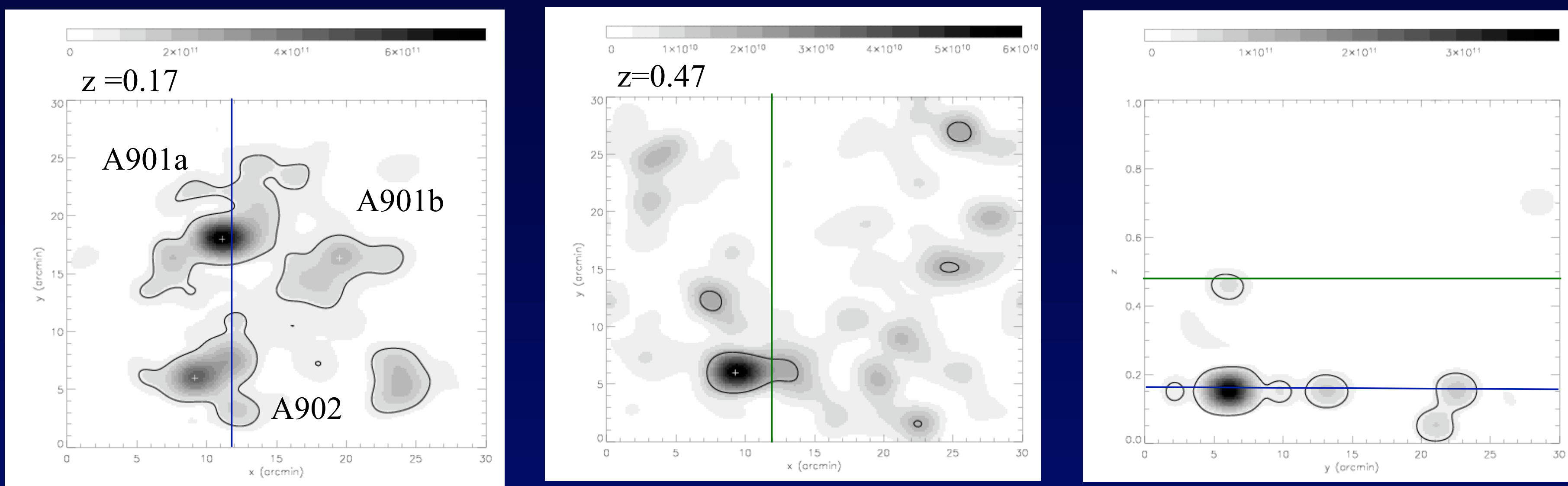


- complex relation between mass and light
- bright cluster counts in agreement with CDM models
- discovery of new clusters

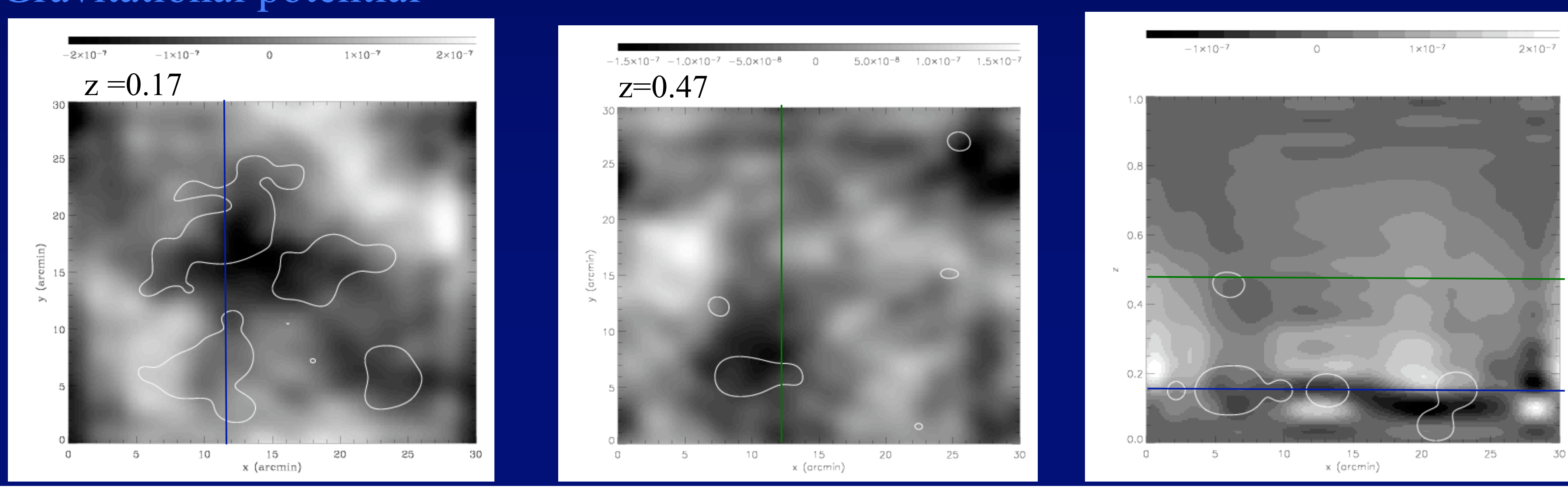
3D Lensing: Mapping

COMBO17: Taylor, Bacon et al. 2004

Luminosity



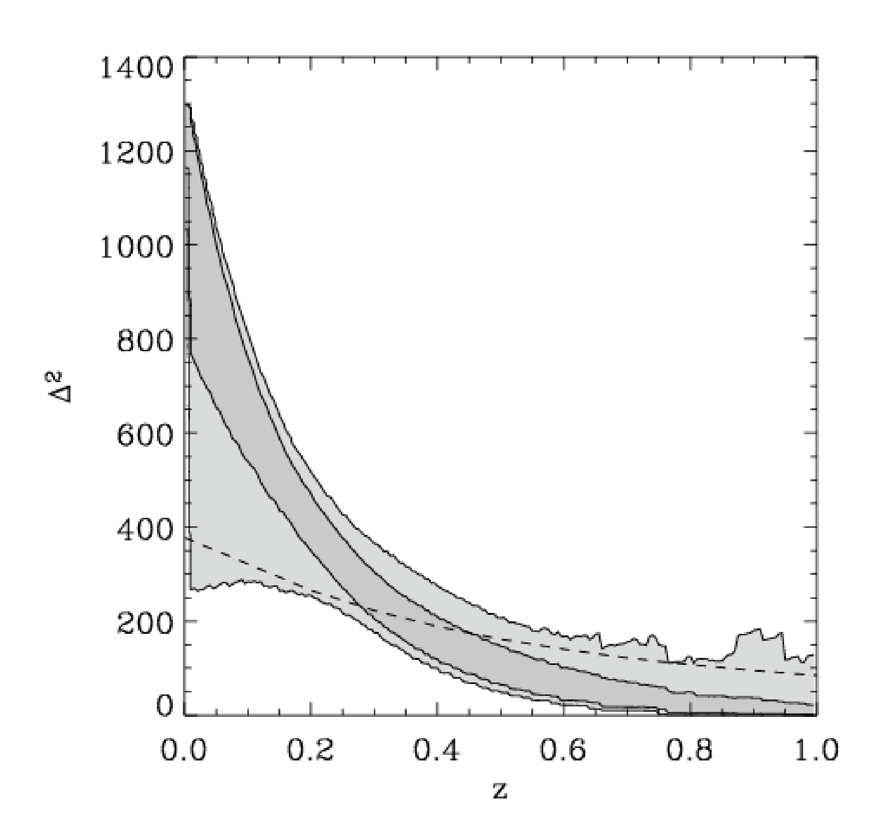
Gravitational potential



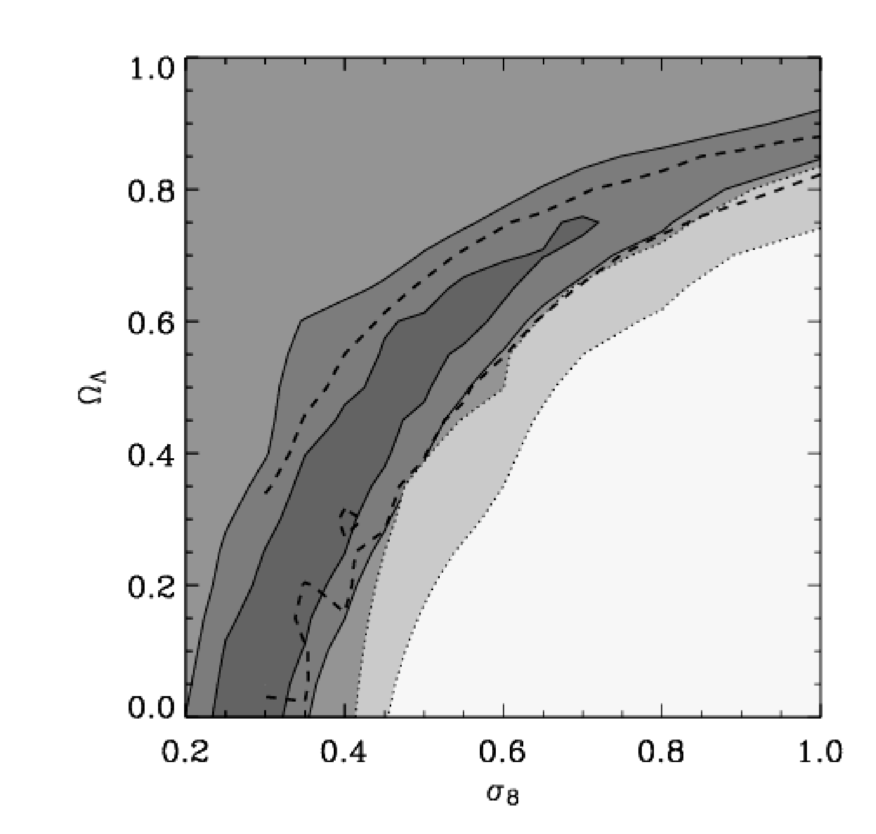
3D Lensing: Statistical

COMBO17: Bacon, Taylor et al. 2004

Growth factor at k=14Mpc^{-1}



Improvements on cosmological constraints



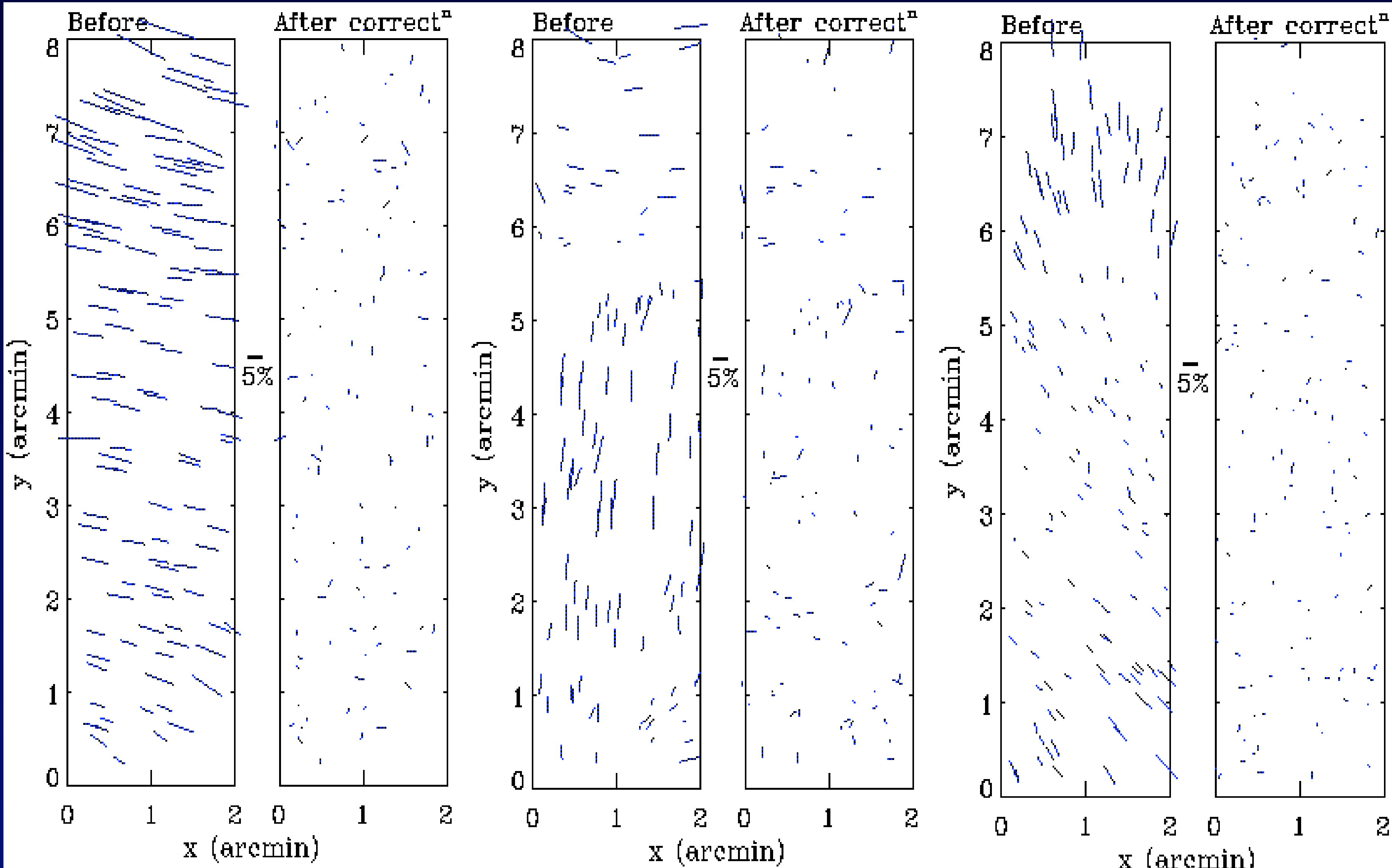
Tomography & cross-correlation cosmography:

Hu 2002, Jain & Taylor 2003, Bernstein & Jain 2003, Hu & Jain 2003

Future Surveys

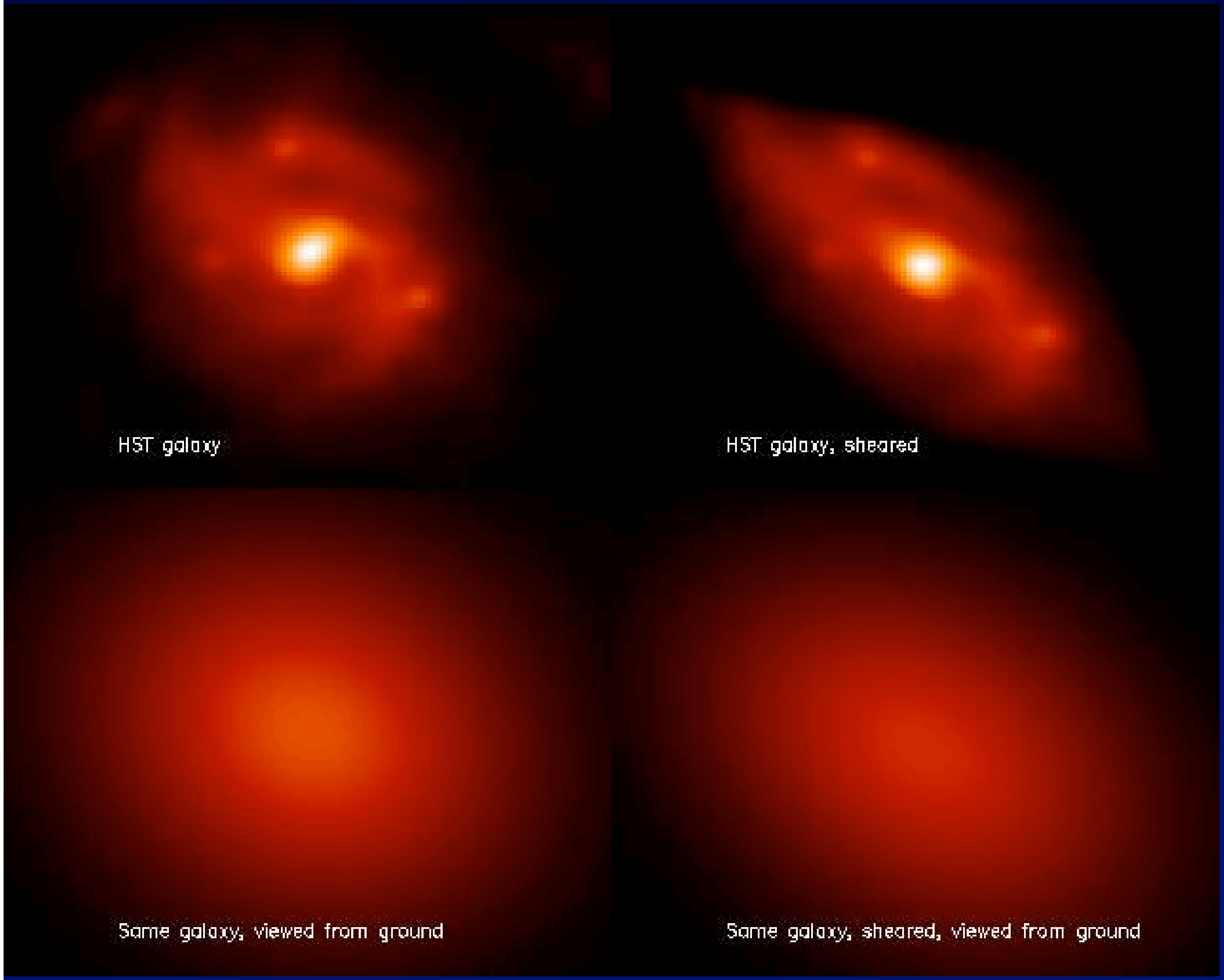
Survey	Diameter (m)	FOV (deg^2)	Area (deg^2)	start
DLS	2?4	2?0.3	28	1999
CFHTLS	3.6	1	172	2003
VST	2.6	1	x100	2004
VISTA	4	2	10000	2007
Pan-STARRS	4?1.8	4?4	31000	2008
LSST	8.4	7	30000	2012
SNAP/JDEM	2 (space)	0.7	1000	2014

Systematic Effects: PSF Anisotropy



Methods: Bonnet & Mellier (1995), Kaiser, Squires & Broadhust (1995), Kuijken (1999), Kaiser (1999), Rhodes, Refregier & Groth (2000), Refregier & Bacon (2001), Bernstein & Jarvis (2001), Hirata & Seljak (2002)

Advantages of Space

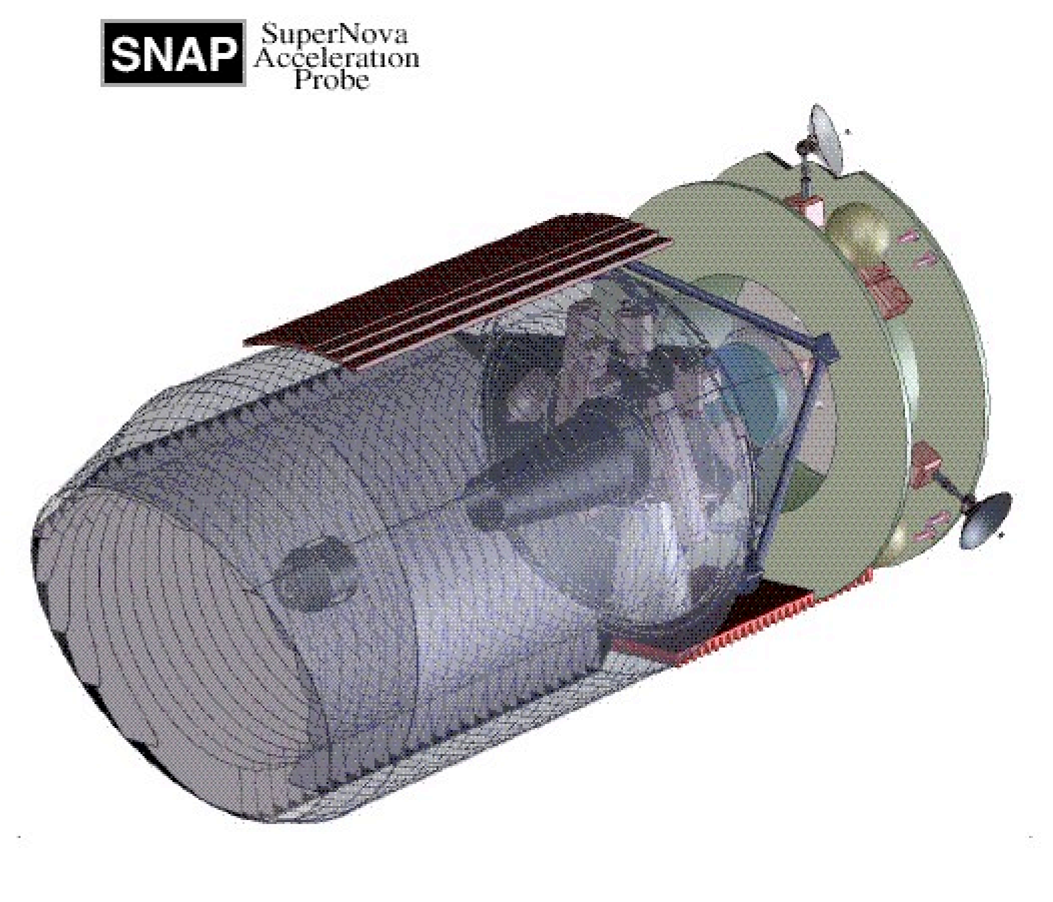


Small and stable PSF

→larger number of resolved galaxies

→ reduced systematics

SNAP/JDEM



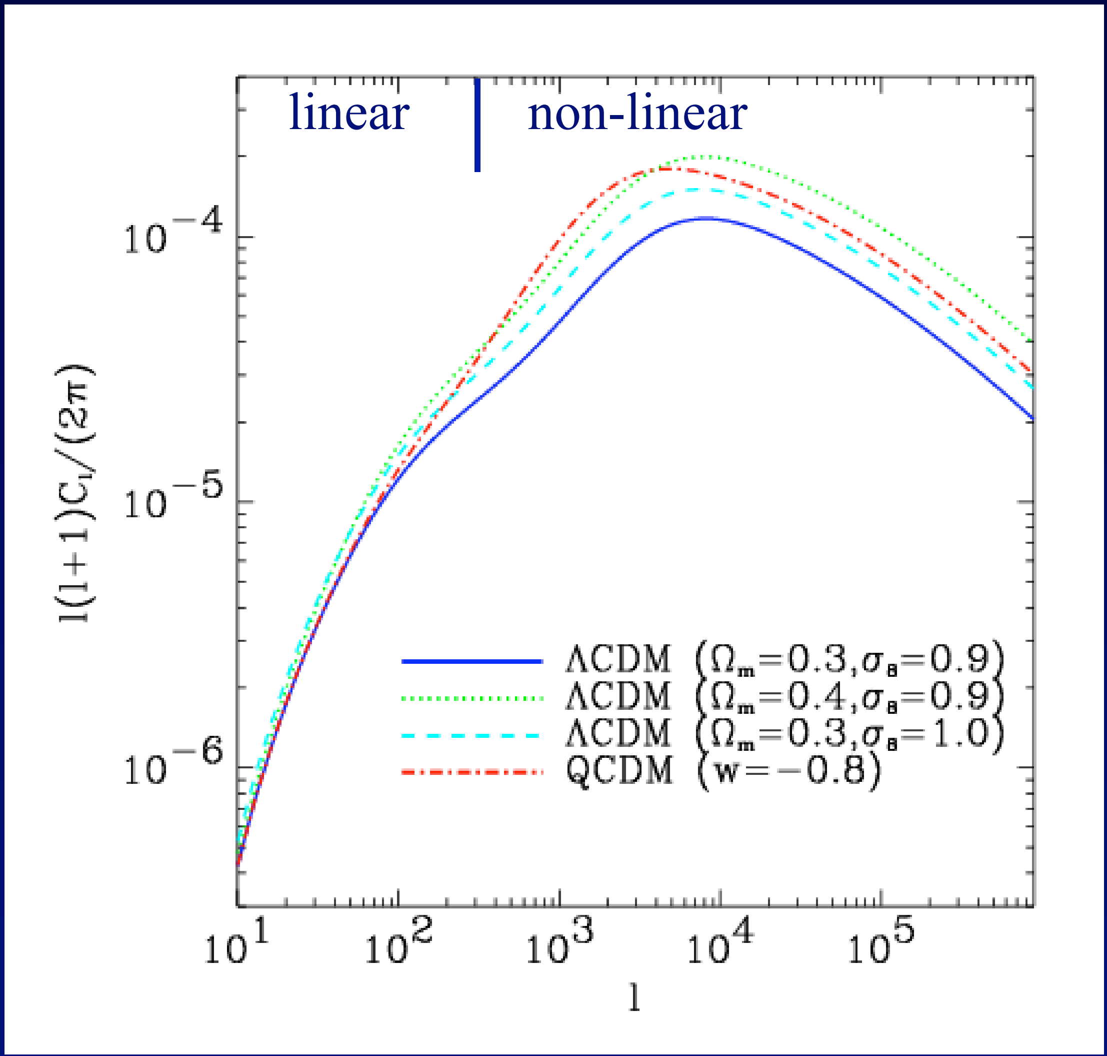
SNAP:

- ~2 m telescope in space
- 1 sq. degree field of view
- 0.35-1.7μm imaging and (low-res) spectroscopy
- 0.1” PSF (FWHM)
- dedicated survey mode:
    - deep (15 deg^2)
    - wide (300 deg^2)

→ Wide field imaging from space

Institutions: LBNL, Goddard, U. Berkeley, CNRS/IN2P3/CEA/CNES, U. Paris VI & VII, Marseille, U. Michigan, U. Maryland, Caltech, U. Chicago, STScI, U. Stockholm, ESO, Instituto Superior Tecnico

Dark Energy and Weak Lensing



Dark Energy equation of state:

$w=p/\rho$ (w=-1 for Λ)

modifies:

- angular-diameter distance
- growth rate of structure
- power spectrum on large scales

a(t)

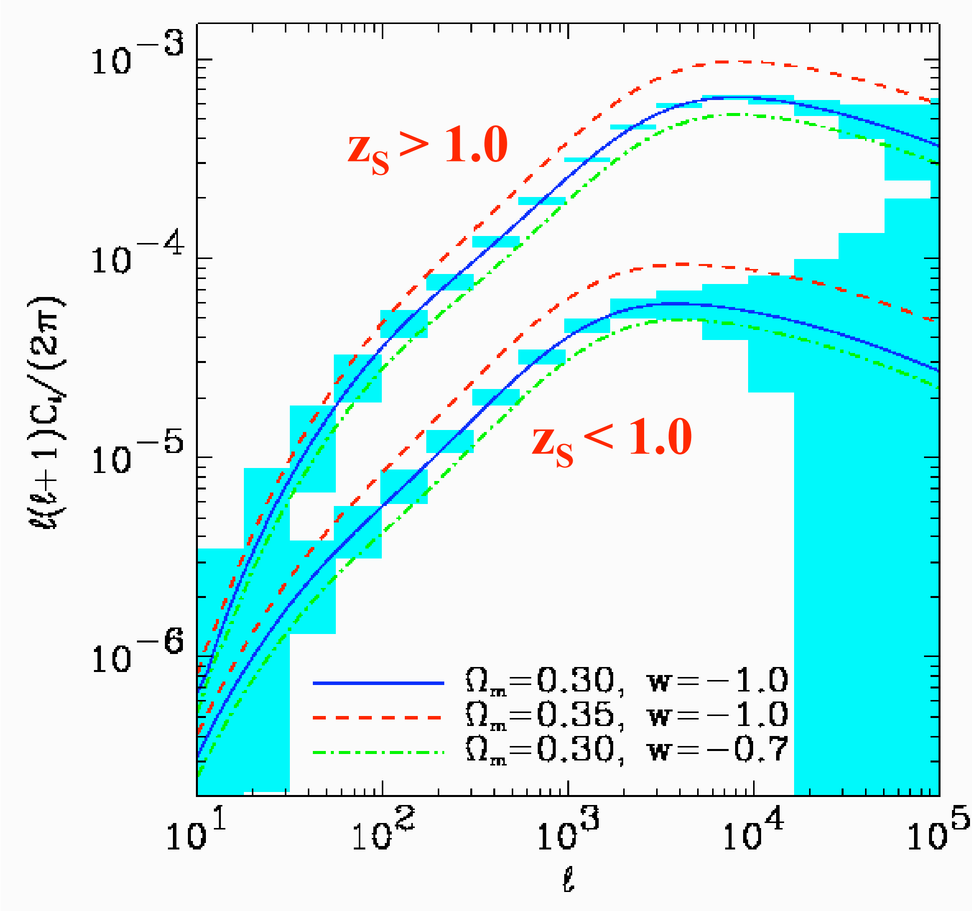
(Ma, Caldwell, Bode & Wang 1999)

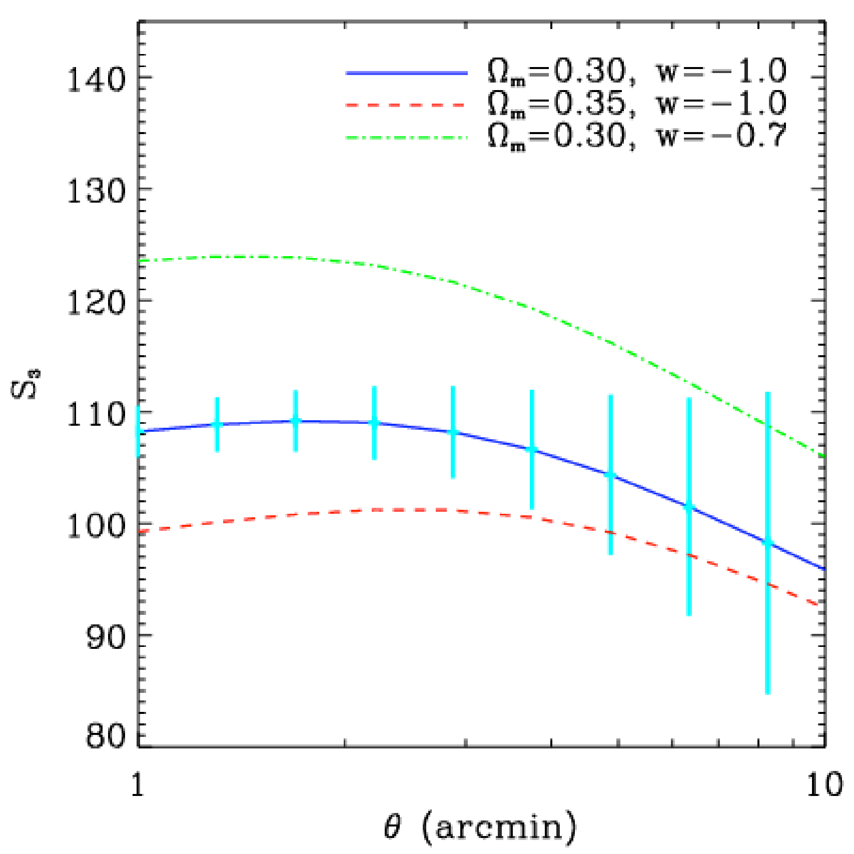
→ w can be measured from the lensing power spectrum

→ But, there are degeneracies between w, Ω_M, σ_8 and Γ

Cf. Hui 1999, Benabed & Bernardeau 2001, Huterer 2001, Hu 2000, Munshi & Wang 2002

Prospect for SNAP

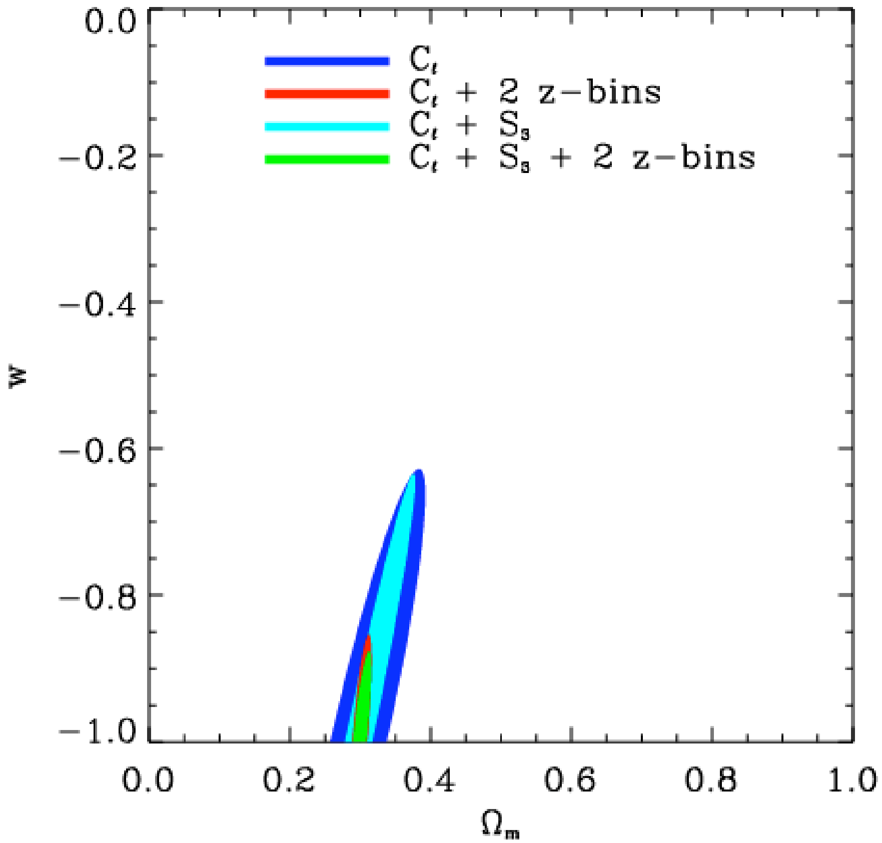


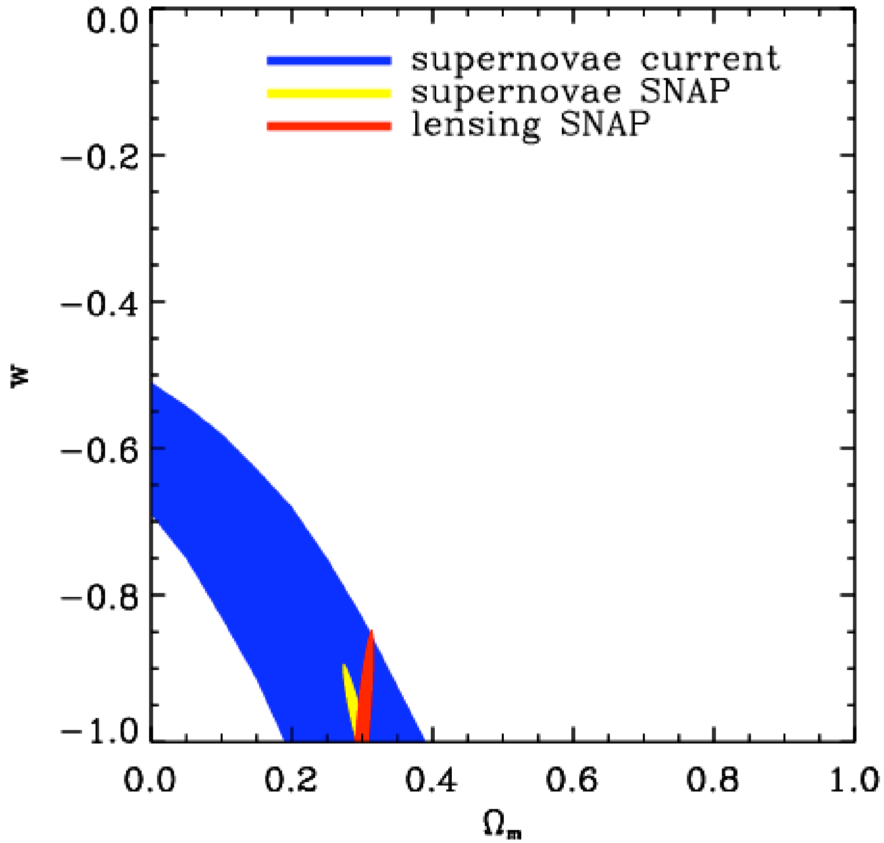


SNAP wide (300 deg^2) Rhodes et al. 2003, Massey et al. 2003, Refregier et al. 2003

→ SNAP will measure the evolution of the lensing power spectrum and skewness and is sensitive to the non-linear evolution of structures

Constraints on Dark Energy

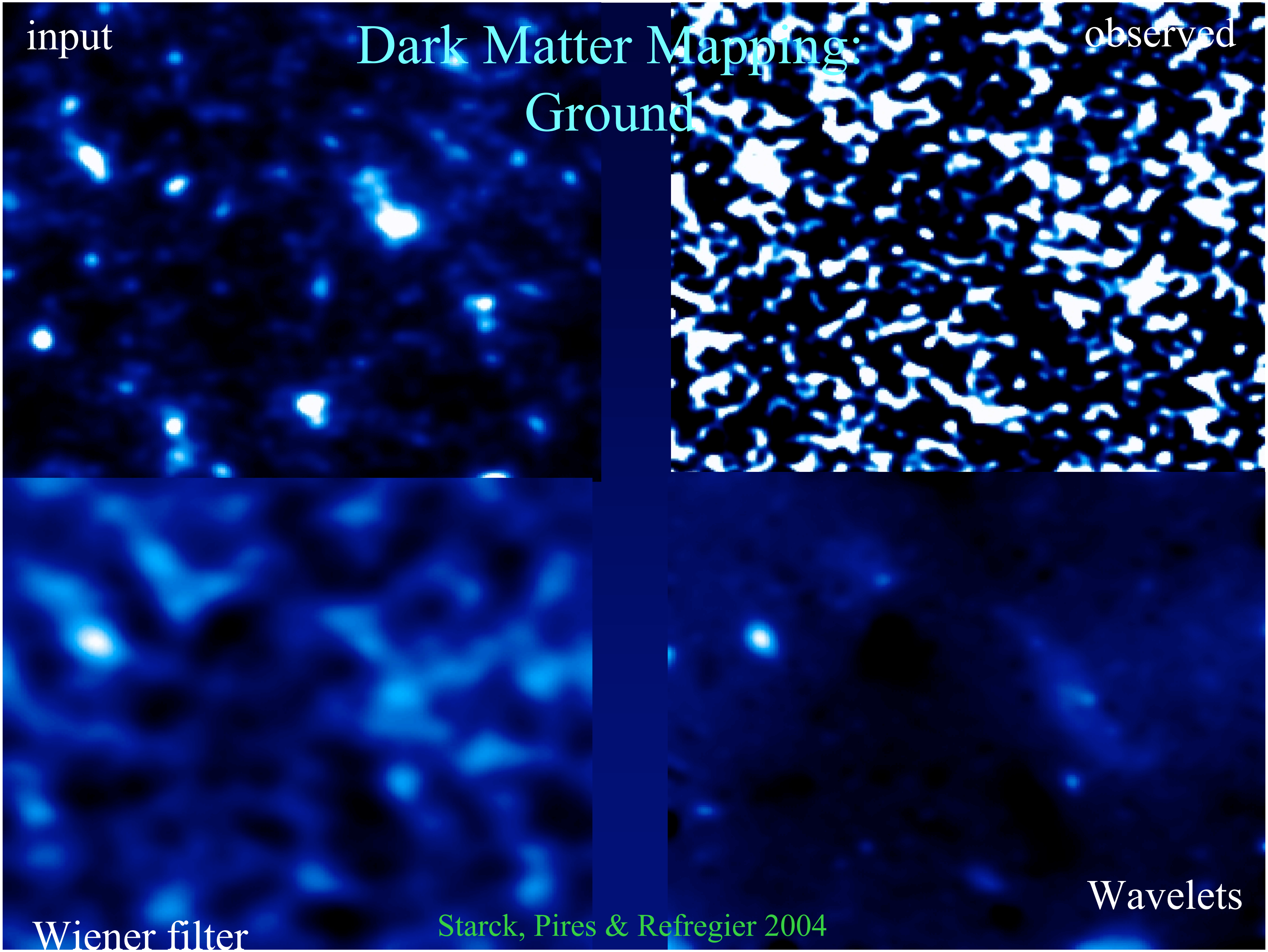




SNAP wide (300 deg^2)

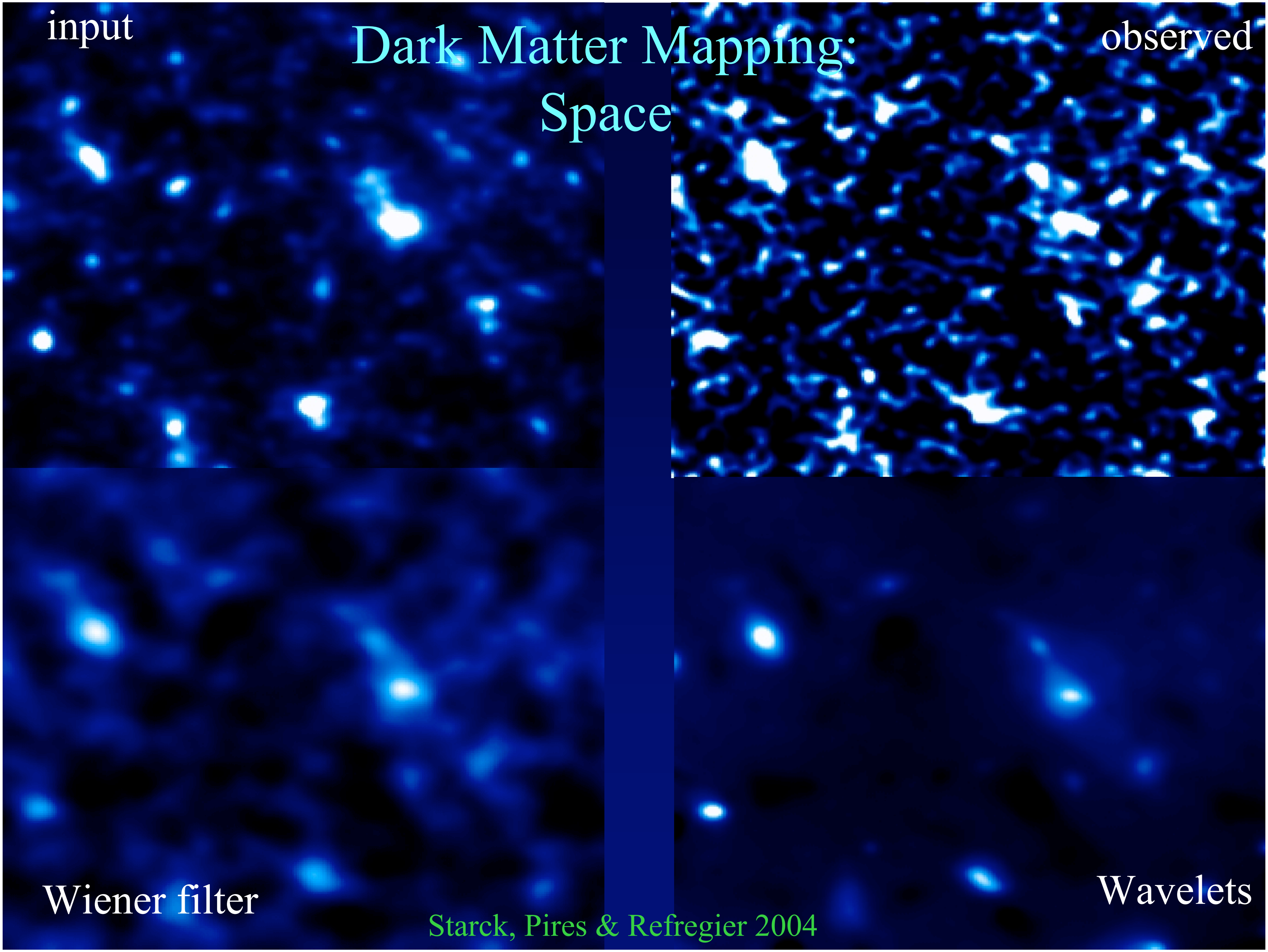
→ Tomography improves constraints on *w* by a factor of 2

→ Cosmic shear constraints complementary to those from SNe



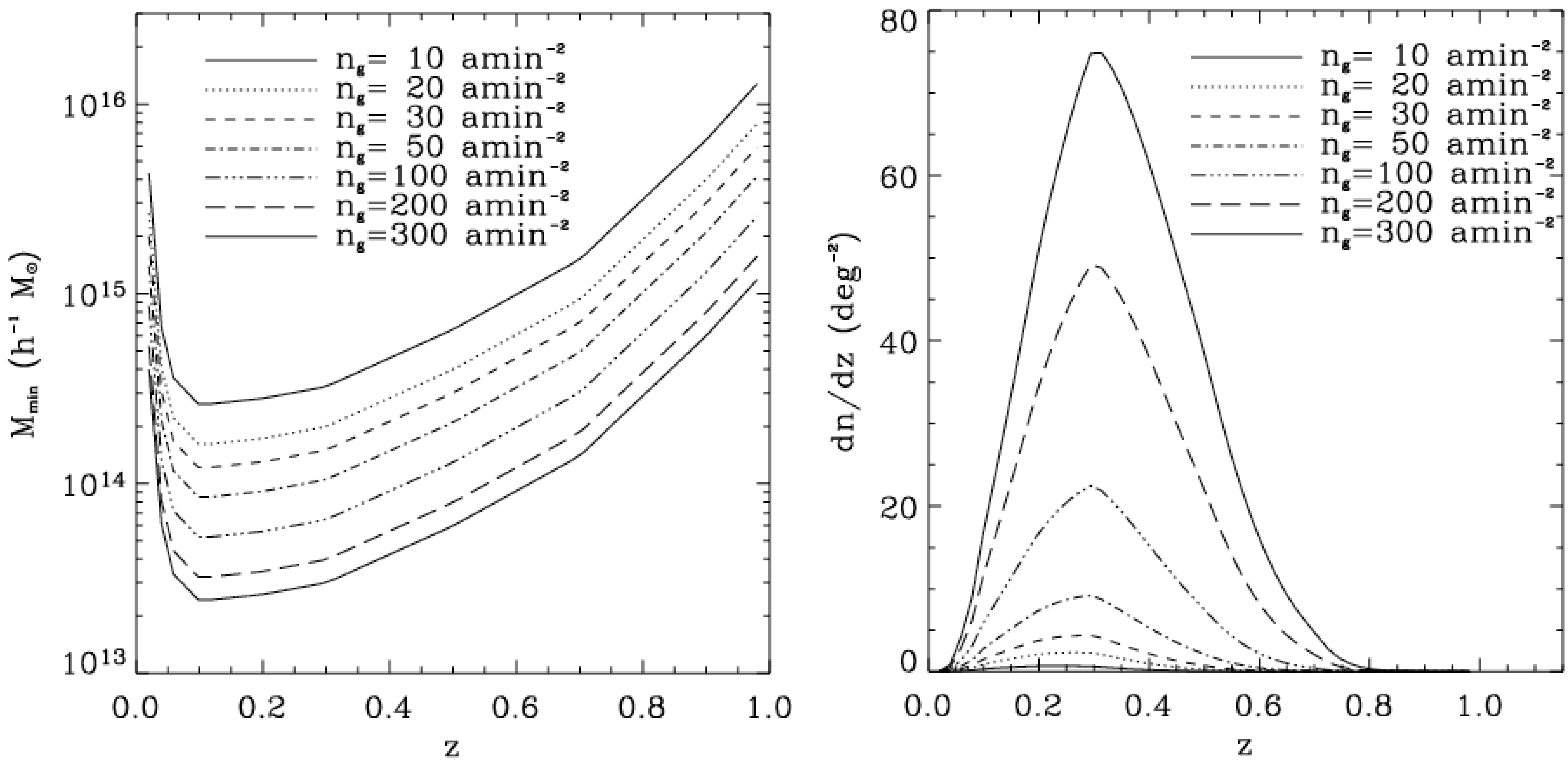
input
Dark Matter Mapping:
Ground
observed
Wiener filter
Wavelets
Starck, Pires & Refregier 2004

Dark Matter Mapping: Space



Starck, Pires & Refregier 2004

Cluster Search with Weak Lensing



Cf. Hamana et al. 2003

Space-based surveys: more sensitive for cluster search, easier to compare to other probes (X-rays, SZ, optical)

Conclusions

- Weak Lensing measures the background of metric fluctuations: distortions of order 10^{-2}, non gaussian, 3D information, probes linear (>10') and non-linear (<10') scales
- Cosmic shear has now been measured with ground-based, space-based optical surveys and with a radio interferometer
- Cosmic shear is sensitive to dark matter and dark energy through geometrical effects and growth factor: distinguish dark matter and energy from modified gravity
- Future surveys offer bright prospects, but we must meet the challenge of systematics → Wide field mission in space: SNAP, JDEM, Beyond Einstein